THE SYNTHESIS AND CHARACTERISATIONS OF POROUS THIOAMIDE-SULFONATED-MODIFIED POLY (ACRYLONITRILE-CO-DIVINYLBENZENE-80) AS POTENTIAL SORBENT TO CAPTURE POLAR ANALYTES

FARHANA SYAKIRAH ISMAIL

FS 2019 49

THE SYNTHESIS AND CHARACTERISATIONS OF POROUS THIOAMIDE-SULFONATED-MODIFIED POLY (ACRYLONITRILE-*CO*-DIVINYLBENZENE-80) AS POTENTIAL SORBENT TO CAPTURE POLAR ANALYTES

By

FARHANA SYAKIRAH ISMAIL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

July 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

THE SYNTHESIS AND CHARACTERISATIONS OF POROUS THIOAMIDE SULFONATED-MODIFIED POLY(ACRYLONITRILE-*CO*-DIVINYLBENZENE-80) AS POTENTIAL SORBENT TO CAPTURE POLAR ANALYTES

By

FARHANA SYAKIRAH ISMAIL

July 2019

Chair : Siti Nurul Ain binti Md. Jamil, PhD
Faculty : Science

Pharmaceuticals contain biologically active components that can pollute watercourses as a result of excretion from individuals and the uncontrolled release of residues from chemical plants. Pharmaceutical residues can persist at low concentrations in the environment, and thus may be potentially harmful to aquatic animals and humans. The control and monitoring of such residues are therefore of prime interest by, for example, solid-phase extraction using solid sorbents to purify and preconcentrate the residues prior to their chemical analysis. In the present work, poly(acrylonitrile-*co*-divinylbenzene-80) (poly(AN-*co*-DVB-80)) sorbents were synthesised by varying the comonomer feed ratios under precipitation polymerisation conditions to deliver a family of porous polymer microspheres. Acrylonitrile confers polar character onto the sorbents, and the acrylonitrile-derived nitrile groups can be chemically transformed *via* polymer-analogous reactions into thioamide and sulphonyl functional groups which make the sorbents even more suitable for the capture of polar analytes, including pharmaceuticals. In the present study, the Fourier transform infrared (FTIR) spectroscopy results confirmed the chemical modification of poly(AN-*co*-DVB-80) (P33) to form thioamide-modified poly(AN-*co*-DVB-80) (TP33) and sulphonation thioamide-HSO_3-modified poly(AN-*co*-DVB-80) (TP33-HSO_3) due to the presence of strong peaks at ~1050 cm^{-1} and ~1154.47 cm^{-1} that were assigned to the stretching vibrations of C=S group and SO_3H group in TP33 and TP33-HSO_3, respectively. The Bruneaur-Emmett-Teller (BET) data demonstrated that the specific surface area of P33 had decreased significantly from 565.0 m^2g^{-1} (P33) to 330.0 m^2g^{-1} (TP33) and 5.9 m^2g^{-1} (TP33-HSO_3) after the chemical modifications were carried out with thiourea and sulphuric acid, respectively. The scanning electron microscopy (SEM) analysis proved that the morphologies structure of the copolymers was retained after chemical modification and sulphonation.

The TP33 had 4.3% of sulphur content due to the chemical modification of the P33 with thiourea, while the amount of sulphur in TP33-HSO_3 was the highest (6.5%) due to the sulphonation with sulphuric acid. The performance of the porous thioamide-sulphonated (TP33-HSO_3) sorbents was demonstrated via the dispersion-solid phase extraction of mefenamic acid (MA), salicylic acid (SA), and diclofenac (DCF) from aqueous medium.

It was found that the highly functionalised TP33-HSO_3 has better extraction compared to the TP33 despite its low specific surface area. Meanwhile, the extraction of pharmaceuticals by using TP33 was better compared to the extraction by using P33, although the specific surface area (SSA) of TP33 is 330.0 m^2g^{-1} and SSA of P33 is 565.0 m^2g^1. This finding showed that in addition to the role of SSA that influenced the extraction process; the presence of active functionalised groups also contributed to the extraction efficiency of the sorbents to extract polar pharmaceuticals. It was found that the maximum extraction for TP33 for MA, SA and DCF were 93.88 $mg.g^1$ (78.23%), 80.07 $mg.g^{-1}$ (66.72%) and 70.70 $mg.g^{-1}$ (58.91%), respectively, while maximum extraction for TP33-HSO_3 were 96.88 $mg.g^{-1}$ (80.73%), 97.15 $mg.g^{-1}$ (80.96%) and 69.51 $mg.g^{-1}$ (57.93%), respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master sains

SINTESIS DAN KARAKTERIA POROS POLI PENGUBAHSUAIAN TIOAMIDA-SULFONATED (ACRYLONITRIL-*KO*-DIVINILBENZANA-80) SEBAGAI POTENSI SORBEN UNTUK ANALISIS KUTUB

Oleh

FARHANA SYAKIRAH ISMAIL

Julai 2019

Pengerusi : Siti Nurul Ain Binti Md. Jamil, PhD
Fakulti : Sains

Farmaseutikal mengandungi komponen aktif secara biologi yang dapat mencemarkan kualiti air akibat daripada pembuangan sisa daripada individu dan pelepasan sisa yang tidak terkawal dari industri kimia. Sisa-sisa farmaseutikal yang dilepaskan secara berterusan pada kepekatan rendah di alam sekitar, berpotensi membahayakan haiwan akuatik dan manusia. Oleh itu, kawalan dan pemantauan sisa-sisa perlu diberi kepentingan utama. Contohnya, pengekstrakan fasa pepejal menggunakan sorben pepejal untuk membersihkan dan mengawal kewujudan sisa. Dalam kajian ini, sorben poli(akrilonitril-*ko*-divinilbenzena-80) poli(AN-*ko*-DVB-80) disintesis dengan mengubah nisbah suapan komonomer di bawah keadaan pempolimeran pemendapan untuk menghasilkan polimer berliang yang berbentuk mikrosfera. Akrilonitril memberi karakter kutub ke dalam sorben, dan kumpulan nitril yang diperolehi daripada akrilonitril boleh diubah secara kimia melalui tindak balas polimer-analogi ke dalam kumpulan fungsi tioamida dan sulfonat yang menjadikan sorben lebih sesuai untuk menangkap analit kutub, seperti farmaseutikal. Dalam kajian ini, spektroskopi *Fourier transform infrared* (FTIR) mengesahkan pengubahsuaian kimia poli(AN-*ko*-DVB-80) (P33) untuk membentuk tioamida terubahsuai poli(AN-*ko*-DVB-80) (TP33) dan tioamida-HSO_3 terubahsuai poli(AN-*ko*-DVB-80) (TP33-HSO_3) disebabkan oleh kehadiran puncak kuat pada ~1050 cm^{-1} dan ~1154.47 cm^{-1} yang dirujuk kepada getaran regangan kumpulan C=S dan kumpulan SO_3H dalam TP33 dan TP33-HSO_3. Data *Bruneaur Emmett-Teller* (BET) menunjukkan kawasan permukaan spesifik P33 menurun dengan ketara dari 565.0 m^2g^{-1} (P33) hingga 330.0 m^2g^{-1} (TP33) dan 5.9 m^2g^{-1} (TP33-HSO3) hasil pengubahsuaian yang dilakukan dengan tiourea dan asid sulfurik. Analisis mikroskopi pengimbasan elektron (SEM) membuktikan bahawa struktur morfologi kopolimer dikekalkan

selepas pengubahsuaian kimia dan sulfonasi. TP33 mempunyai 4.3% kandungan sulfur kerana pengubahsuaian kimia P33 dengan tiourea, manakala jumlah sulfur dalam TP33-HSO_3 adalah yang tertinggi (6.5%) disebabkan oleh sulfonasi dengan asid sulfurik. Prestasi sorben tioamida tersulfat (TP33-HSO_3) poros dibuktikan melalui pengekstrakan penyerakan-fasa pepejal terhadap asid mefenamik (MA), asid salisilik (SA) dan diklofenak (DCF) daripada media akueus.

TP33-HSO_3 telah didapati mempunyai pengekstrakan yang lebih baik berbanding pengekstrakan TP33 walaupun mempunyai kawasan permukaan spesifiknya yang rendah. Sementara itu, pengekstrakan farmaseutikal menggunakan TP33 lebih baik berbanding pengekstrakan dengan menggunakan P33, walaupun kawasan permukaan spesifik (SSA) TP33 adalah 330.0 m^2g^{-1} dan SSA P33 adalah 565.0 m^2g^{-1}. Dapatan ini menunjukkan bahawa, di samping peranan SSA yang mempengaruhi proses pengekstrakan; kehadiran kumpulan yang berfungsi secara aktif juga menyumbang kepada kecekapan pengekstrakan untuk mengekstrak farmaseutikal kutub. Didapati bahawa pengekstrakan maksimum oleh TP33 untuk MA, SA dan DCF adalah 93.88 $mg.g^{-1}$ (78.23%), 80.07 $mg.g^{-1}$ (66.72%) dan 70.70 $mg.g^{-1}$ (58.91%), manakala pengekstrakan maksimum oleh TP33-HSO_3 adalah 96.88 $mg.g^{-1}$ (80.73%), 97.15 $mg.g^{-1}$ (80.96%) dan 69.51 $mg.g^{-1}$ (57.93%).

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful

First of all, thanks to Allah S.W.T because giving me an opportunity to complete the thesis making just in time. Although I had to face with a lot of difficulties along to accomplish this task, I still manage to finish it successfully. Say: "*surely my Prayer, my sacrifice, my life, and my death are all for God, the Lord of all Creations*" (Surah Al-Anam, 162).

I would like to express my gratitude to my parents, Ismail Bin Md. Sohot and Noormah Binti Kassim who always support, motivate and pray for my great success. They are always by my side when I needed them and served as my inspiration in pursuing this research. I would like to thank my supervisor, Dr. Siti Nurul Ain Binti Md. Jamil for her sincere guidance and providing necessary information regarding this research. It was a great honor to complete this Master work under her supervision. Special thanks to my co-supervisors, Dr. Sazlinda Kamaruzzaman and Prof. Dr. Luqman Chuah Abdullah for their endless support and understanding throughout my research period. To all my labmates; Nida, Afiqah and Hanisah. I acknowledge them for their cooperation which helped me to a very great extent to accomplish this research.

I certify that a Thesis Examination Committee has met on 26-July-2019 to conduct the final examination of Farhana Syakirah on her thesis entitled "The synthesis and Charactterisation of Porous Thioamide-Sulphonated-Modified Poly(AN-*co*-DVB-80) as Potential Sorbent to Capture Polar Analytes" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master's Degree.

Members of the Thesis Examination Committee were as follows:

Jaafar Bin Abdullah, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Norizah Binti Abdul Rahman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Chia Chin Hua, PhD
Associate Professor
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

_____
(ROBIAH BINTI YUNUS, PhD)
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Siti Nurul Ain Md. Jamil, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Luqman Chuah Abdullah, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sazlinda Kamaruzzaman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: _____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: _____

Signature: _____
Name of Member of Supervisory Committee: _____

Signature: _____
Name of Member of Supervisory Committee: _____

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AN	Acrylonitrile
DVB-80	Divinylbenzene-80
BPO	Benzoyl Peroxide
PAN	Polyacrylonitrile
P29	Poly(DVB)
P35	Poly(AN)
P30	Poly(AN-*co*-DVB-80) (0.20:0.80)
P31	Poly(AN-*co*-DVB-80) (0.25:0.75)
P32	Poly(AN-*co*-DVB-80) (0.4:0.60)
P33	Poly(AN-*co*-DVB-80) (0.50:0.50)
P34	Poly(AN-*co*-DVB-80) (0.80:0.20)
TP33	Thioamide-modified poly(AN-*co*-DVB-80)
TP33-HSO_3	Thioamide-HSO_3-modified poly(AN-*co*-DVB-80)
FTIR	Fourier Transform Infrared
BET	Brunauer-Emmett-Teller
SEM	Scanning electron microscope
MA	Mefenamic Acid
SA	Salicylic acid
DCF	Diclofenac
NSAID	Nonsteroidal anti-inflammatory drug
STP	Sewage treatment plant
dSPE	Dispersive solid-phase extraction
HPLC	High-performance liquid chromatography
CNTs	Carbon nanotubes
NaOH	Sodium hydroxide
LiAlH	Aluminum hydride
TG	Thermogravimetric
TG-DTG	Thermogravimetry-derivative thermogravimetry
API	Active pharmaceutical ingredients

CHAPTER 1

INTRODUCTION

1.1 Synthesis of Sorbent

In this study, poly(AN-*co*-DVB-80) (Figure1.1) was formed *via* precipitation polymerisation. Precipitation polymerisation is a synthesis method that is used to form crosslinked monodisperse polymer microsphere (0.1-1.0 μm range). This method provides advantages to the copolymer, which involves non-incorporation of steric stabiliser or electronic surfactant. Therefore, the surface of the copolymer formed is free from any contaminant from surfactant-derived ionic charges. In addition, the morphologies of the polymer particles can be tuned by adjusting the precipitation polymerisation conditions. The formation of monodisperse particles with a narrow particles size distribution is advantageous for column packing in chromatography.

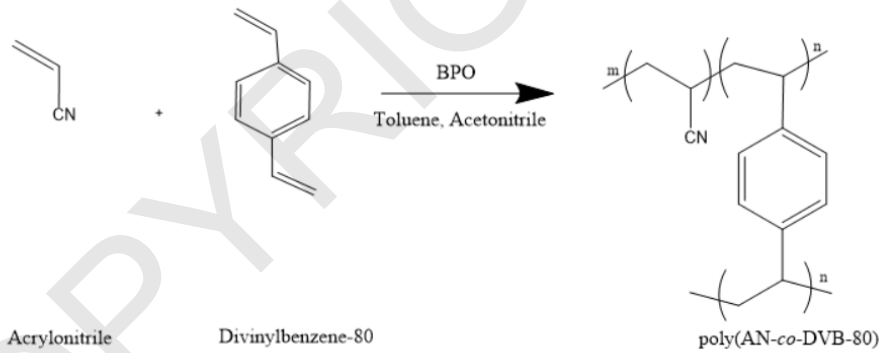


Figure 1.1: The Synthesis of Poly(AN-*co*-DVB-80)

In the present study, the monomers used were acrylonitrile (AN) and divinylbenzene (DVB-80). The initiator used was benzoyl peroxide (BPO), and the medium was a mixture of acetonitrile and toluene. The initiator (BPO) was utilized to initiate the polymerisation. The mixture of acetonitrile and toluene served as porogen and medium for precipitation polymerisation. Acrylonitrile (Figure 1.2) is an organic compound with the formula of CH_2=CHCN, which is colorless, volatile, flammable, and water-soluble liquid at room temperature. It consists of a vinyl group linked to a nitrile and widely used in industry to produce elastomers, resins and to manufacture carbon fibres for aircraft, defense and aerospace industries.

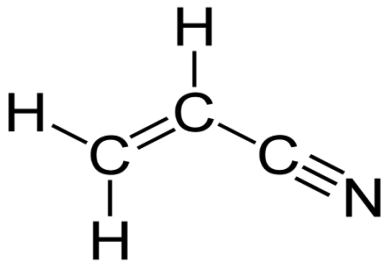


Figure 1.2: Molecular Structure of Acrylonitrile

DVB-80 (Figure 1.3) acts as a crosslinker agent, which helps in maintaining the firmness of the PAN system. For instance, the inclusion of DVB-80 units in the PAN system disrupts the nitrile-nitrile dipolar interaction along with the PAN system and consequently facilitate the access of modification reagents into polymer chains during the chemical modification process. The addition of DVB-80 is also to increase the porosity of PAN-based adsorbent and consequently to make adsorption more efficient. Poly(AN-*co*-DVB-80) porous particles provide micropore content which has a high specific surface area and thus has more interaction points with the analytes to be adsorbed.

Figure 1.3: Molecular Structure of Divinylbenzene-80 (DVB-80)

The copolymer formed was chemically modified by thiourea (Figure 1.4). Thiourea is a strong hydrogen bond donor, which can form hydrogen bonds with many groups such as carboxyl, nitro and in particular phosphate groups due to its $–NH_2$ and sulphur group that can coordinate with pharmaceuticals to form a complex compound. Thus, the chemically modified copolymer with thiourea is expected to act as an active sorbent to adsorb pharmaceutical residues. It was demonstrated that the adsorption performance of these adsorbents was enhanced to some extent owing to their strong complexation interaction with a polar compound such as pharmaceuticals. In addition, by the presence of thiourea in a copolymer may also increase the selectivity of the copolymer as a sorbent towards the polar compound.

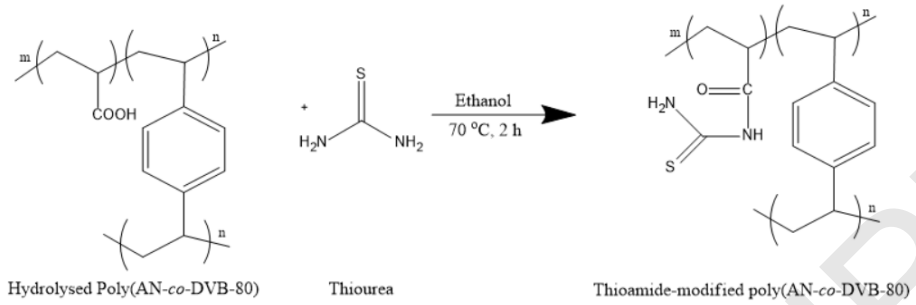


Figure 1.4: Chemical Modification of Poly(AN-*co*-DVB-80) With Thiourea

The adsorbent that has been modified with thiourea promotes ion exchange interactions with the anionic compounds (analytes). Pharmaceuticals were adsorbed at the active site of the thioamide-modified poly(AN-*co*-DVB-80) which were at C=S and NH groups. Therefore, thioamide-modified poly(AN-*co*-DVB-80) is expected to be selective for the adsorption of anionic compounds in pharmaceuticals.

Sulphonation was performed on the modified copolymer to form thioamide-HSO_3-modified poly(AN-*co*-DVB-80) (Figure 1.5). Sulphonated polymer leads to a better ion exchange resin which the polymers having positively and negatively charged functional group that can exchange their mobile ions equal charge with the surrounding medium. In addition, introducing sulphonic acid group into the polymer will transform the polymer into the ionomers. An ionomer is a polymer composed of repeat units of both electrically neutral repeating units and ionized units covalently bonded to the polymer backbone as pendant group moieties. These ionomers have excellent chemical and thermal stability and can absorb large amounts of water. They are often used as ion-selective membranes. Other than that, introducing a sulphonic group into the polymer can improve the hydrophilicity of the polymer. Incorporation of polar groups by sulphonation favors water uptake, thus inducing stronger interactions between the resin and oppositely charged ions in pharmaceuticals. The sulphonic acid group leads to the formation of proton and cation conductivity, which ideal for the membranes like proton exchange membrane fuel cells. A sulphonated polymer is highly used in membranes for fuel cells and electrodialysis, exchange resins and catalysts, surgical instruments and wound healing dressings.

The sulphonation can take place before polymerisation (pre-sulphonation) or *via* post-sulphonation which gives direct influence on the degree of the sulphonation and properties of the sulfonated copolymer. Most of the post-sulphonation processes are conducted in a homogenous way which allows the use of less reactive reagent, like complexes of SO_3 with amines or phosphates.

Polymers can be sulphonated with a large range of reagent with different selectivity and reactivity.

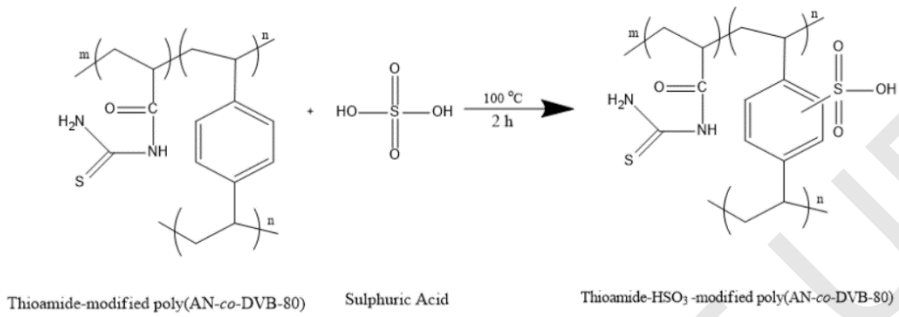


Figure 1.5: Sulphonation of Thioamide-Modified Poly(AN-*Co*-DVB-80) With Sulphuric Acid

1.2 Targeted Compound in This Study

Figure 1.6, 1.7, and 1.8 show the molecular structure of the targeted compounds that are mefenamic acid (MA), salicylic acid (SA) and diclofenac (DCF), respectively. MA is an anthranilic acid derivative and belongs to a nonsteroidal anti-inflammatory drug (NSAID). It is used for the treatment of analgesia. Other than that, it also used as an antirheumatic and antipyretic drug, for the treatment of dental pain, headache, and dysmenorrheal (Naveed and Qamar, 2014). MA has side effects that cause headaches, nervousness, vomiting, diarrhea, hematemesis, and haematuria. SA is a medication that widely used as a removal of the outer layer of the skin such as ringworm, warts, acne, and dandruff. SA causes stomach ache, diarrhea, and headache if excessively consumed. DCF is a NSAID that is used to reduce inflammation, joint stiffness caused by arthritis and as an analgesic reducing pain in a certain condition. DCF causes side effects like chest pain, weakness, coughing up blood, and vomit if excessively consumed. In addition, DCF is also known as a compound that affects organ histology and gene expression in fish at concentrations as low as 1 $\mu g \cdot L^{-1}$.

MA, SA and DCF are some of the pharmaceutical residues that may affect the aquatic environment and water supplement. In Malaysia, MA, SA and DCF were detected in the Langat River with a concentration of Sewage Treatment Plant (STP) effluent 146 ng/L, 36 ng/L and 217 ng/L, respectively (Al-Odaini *et al.*, 2010).

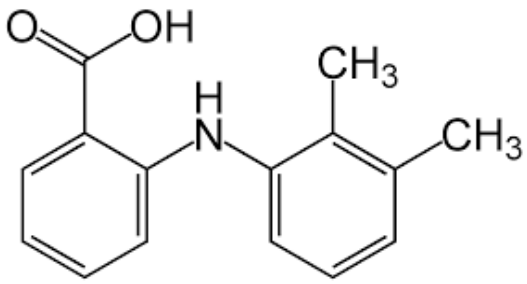
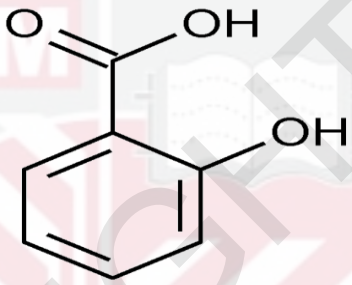
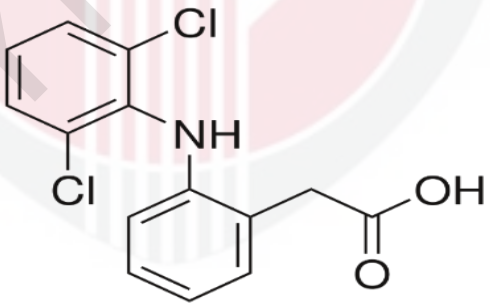


Figure 1.6: Molecular Structure of MA



1.7: Molecular Sturucture of SA



1.8: Molecular Structure of DCF

1.3 Dispersive Solid Phase Extraction (dSPE) Techniques

In this study, dispersive solid-phase extraction (dSPE) technique was used for the extraction process. dSPE is a sorbent-based technique that is widely applied in sample preparation for both samples clean up or analyte preconcentration. It shows considerable benefits over conventional solid phase extraction (SPE), especially in terms of the simplicity of the procedure. This technique is based on the dispersion of a solid sorbent in liquid samples in the extraction isolation and clean-up of different analytes from complex matrices. DSPE is used in pretreatment technique for the analysis of several compounds, for example, extraction, isolation, clean-up, and preconcentration of residues of veterinary drugs, animal tissue, foodstuff, etc. DSPE has a wide range of applications in several fields because it is considered as a selective, robust, and versatile technique.

1.4 Research Problems and Research Approaches

The presence of pharmaceutical manufacturers in Malaysia may lead to the discharge of pharmaceutical waste into water sources. On the other hand, the pharmaceutical waste is also introduced into the water sources by excretion from individuals or patients that have consumed pharmaceutical compounds for medicinal purposes. Pharmaceuticals contain an active ingredient that might cause toxicity and pollutes the water. Pharmaceuticals exist in the long term with low concentration and may harmful to aquatic life and human. Most of the factories in Malaysia are inefficient in the removal of these pollutants since the primary and secondary treatments usually applied were not designed for this purpose. However, since legislation on the discharge of pharmaceuticals is expected to come out soon, it is necessary to find efficient treatments (Coimbra *et al.*, 2018). Thus, many works were dedicated by researcher to enhance the uptake of low concentration of pharmaceuticals in water by designing various adsorbents such as activated carbon, carbon nanotubes (CNTs) and zeolites (Basheer, 2018).

However, the major disadvantages of these adsorbents are due to their low adsorption capacities, relatively weak interactions with ions, and difficulties of separation and regeneration from water. Ion-exchange resins were able to remove ions substantially; however, they had low selectivity and showed a high degree of swelling and poor mechanical stability (Samiey *et al.*, 2014).

To overcome these limitations, porous and highly functionalised poly(AN-*co*-DVB-80), microspheres particles were prepared in the present work. The DVB-80 monomer acted as a crosslinking agent that helped to maintain the firmness and develop a three-dimensional molecule (and hence develop porosity) in the PAN copolymer system. The efficacy of the adsorption capacity was expected to improve with the development of the porosity of the PAN-based polymeric adsorbent. The porous resin had active functional groups upon its chemical treatment with thiourea (on the nitrile units) to develop a basic anion exchanger of poly(AN-*co*-DVB-80) matrix. Thioamide was selected to instill three amine groups on each of the cyano group with longer pendant chains. The anion exchangers which carried cationic groups ($\equiv N^+$, $=NH^+$ and $-NH_2^+$) were expected to attach to the reversely charged counterions by electrostatic interactions. In addition, sulphuric acid was introduced onto the thioamide-modified poly(AN-*co*-DVB-80) by sulphonation to increase the ion exchange resin and induce stronger interactions with the polar compounds (Patiño *et al.*, 2016).

In the present work, a multi-residue method based on dSPE followed by HPLC analysis was used to determine the detection of the pharmaceutical residues during the extraction.

1.5 Objectives of The Study

1. To synthesis porous poly(AN-*co*-DVB-80) copolymer *via* precipitation polymerisation.
2. To chemically modify the poly(AN-*co*-DVB-80) copolymer with thiourea to form thioamide-modified poly(AN-*co*-DVB-80) and sulphonated with sulphuric acid to form thioamide-HSO_3-modified poly(AN-*co*-DVB-80).
3. To evaluate the performance of chemically-modified poly(AN-*co*-DVB-80) to capture pharmaceuticals *via* dispersive solid-phase extraction (dSPE) technique.

1.6 Project Motivation and Research Novelty

In the present work, the novel thioamide-modified poly(AN-*co*-DVB-80) and thioamide-HSO_3-modified poly(AN-*co*-DVB-80) were produced and used for the extraction of pharmaceuticals to evaluate the performance of the adsorbents. Thus, the polymeric material that is produced in this work is expected to have a potential for application in environmental clean-up, specifically to extract polar pharmaceuticals.

Preparation of porous and highly functionalised poly(AN-*co*-DVB-80) by using thiourea and sulphuric acid has not been reported elsewhere. The presence of the primary amines in thioamide groups is expected to form various active cationic groups ($\equiv N^+$, $=NH^+$ and $-NH_2^+$) for the capture of anionic polar compounds. The presence of sulphur in the thioamide group and OSO_2 from sulphonation is expected to form various anionic groups ($-SH^-$, $R\text{-}S\text{-}H^{-2}$, $O\text{-}SO_2^{-2}$) for the capture cationic polar compounds. In addition, S groups from the thioamide group can be used to form hydrogen bond and in water and can coordinate with pharmaceutical to form complex form.the sulphonation will enhance the ion exchange of the polymer and promoted better interaction with the pharmaceutical residues.

The combination of porous characteristic and highly functionalised copolymer is expected to produce adsorbent with high capacity and selectivity to extract pharmaceuticals due to the pharmaceuticals' potential to bind through either the S or the amine N atoms in thioamide modified poly(AN-*co*-DVB-80) and $-SO_3$ in thioamide-HSO_3-modified poly(AN-*co*-DVB-80).

REFERENCES

Akin, D., Yakar, A. and Gunduz, U. (2015) Investigation of desorption kinetics and equilibrium of an anionic dye from magnetic polymer adsorbents. *Proceedings of the 14th International Conference on Environmental Science and Technology.*

Al-Odaini, N. A., Zakaria, M. P., Yaziz, M. I. and Surif, S. (2010) Multi-residue analytical method for human pharmaceuticals and synthetic hormones in river water and sewage effluents by solid-phase extraction and liquid chromatography–tandem mass spectrometry. *Journal of Chromatography A.* 1217**.** 6791-6806.

Al-Qaim, F. F., Abdullah, M. P., Othman, M. R., Latip, J. and Afiq, W. M. (2013) Development of analytical method for detection of some pharmaceuticals in surface water. *Tropical Journal.* 12**.** 609-616.

Al-Qaim, F. F., Abdullah, M. P. and Othman, M. R. O. (2012) Analysis of different therapeutic classes using liquid chromatography-mass spectrometry in aquatic environment : a review. *International Journal of Pharmacy and Pharmaceutical Sciences.* 4**.** 0975-1491.

Amouzgar, P., Yuan Wong, M., Horri, B. and Salamatinia, B. (2016) Advanced Material for Pharmaceutical Removal from Wastewater. *Smart Materials From Water Applications.* DOI:10.1002/9781119041214.

Anirudhan, T. S. and Ramachandran, M. (2008) Synthesis and Characterization of Amidoximated Polyacrylonitrile/Organobentonite Composite for Cu(II), Zn(II), and Cd(II) Adsorption from Aqueous Solutions and Industry Wastewaters. *Industrial & Engineering Chemistry Research.* 47**.** 6175-6184.

Anumol, T., Lehotay, S. J., Stevens, J. and Zweigenbaum, J. (2017) Comparison of veterinary drug residue results in animal tissues by ultrahigh-performance liquid chromatography coupled to triple quadrupole or quadrupole–time-of-flight tandem mass spectrometry after different sample preparation methods, including use of a commercial lipid removal product. *Analytical and Bioanalytical Chemistry.* 409**.** 2639-2653.

Arsalani, N., Rakh, R., Ghasemi, E. and Akbar Entezami, A. (2009) Removal of Ni(II) From Synthetic Solutions Using New Amine-containing Resins Based on Polyacrylonitrile*. Iranian Polymer Journal*. 18(8).

Avdeef, A. and John, W. a. S. (2012) Absorption and drug development : solubility, permeability, and charge state*. (second edition ed.). Wiley*.

Bagheri, B., Abdouss, M., Mohammadi Aslzadeh, M. and Mousavi Shoushtari, A. (2010) Efficient Removal of Cr3+, Pb2+ and Hg2+ Ions from Industrial Effluents by Hydrolyzed/Thioamidated Polyacrylonitrile Fibres. *Iranian Polymer Journal.* 19(12):911-925

Basheer, A. A. (2018) New generation nano-adsorbents for the removal of emerging contaminants in water. *Journal of Molecular Liquids.* 261**.** 583-593.

Beydaghi, H., Javanbakht, M. and Badiei, A. (2014) Cross-linked poly(vinyl alcohol)/sulfonated nanoporous silica hybrid membranes for proton exchange membrane fuel cell. *Journal of Nanostructure in Chemistry.* 4**.** 97.

Bozena, N. K., Luczyiki, J., W.Trochimczuk, A. and Wojaczynska, M. (1987) Gas chromatographic properties of porous polyacrylonitrile and divinylbenzene copolymers. *Journal of Chromatography.* 308-315.

Cháfer-Pericás, C., Balaguer, Á., Maquieira, Á. and Puchades, R. (2013) Dispersive solid-phase extraction and immunoassay with internal reference calibration using fatty acid-coated inorganic fluorescent nanoparticles. *Analytical Biochemistry.* 432**.** 31-37.

Chen, D., Wang, S., Xiao, M., Meng, Y. and Hay, A. S. (2011) Novel polyaromatic ionomers with large hydrophilic domain and long hydrophobic chain targeting at highly proton conductive and stable membranes. *Journal of Materials Chemistry.* 21**.** 12068-12077.

Chen, R., Li, G., Yang, S., Xiong, M. and Jin, J. (2017) Sulfonated poly(arylene ether sulfone) polymers containing 3,4-difluoro-phenyl moiety as proton exchange membranes. *Solid State Ionics.* 300**.** 157-164.

Coimbra, N. R., Escapa, C. and Otero, M. (2018) Adsorption Separation of Analgesic Pharmaceuticals from Ultrapure and Waste Water: Batch Studies Using a Polymeric Resin and an Activated Carbon. *Polymers.* 10.

Deng, S., Bai, R. and Chen, J. P. (2003) Animated polyacrylonitrile fibers for lead and copper removal. *Langmuir.* 5058-5064.

Derrick, M. R., Stulik, D. and Landry, J. M. (2000) Infrared spectroscopy in conservation science*. Geety Publication.* 248*.*

Dong, M. W. (2016) *A universal reversed-phase HPLC method for pharmaceutical analysis.*

Ebenezar, J. (2016) Recent Trends in Materials Science and Applications: nanomaterials, Crystal Growth, Thin films, Quantum Dots, & Spectroscopy *(Proceedings ICRTMSA 2016).* Gewerbestrasse 11, 6630 Cham, switzerland, Springer Nature.

El-Newehy, M. H., Abdullah, A. and Salem, S. a.-D. (2014) Optimization of amine-terminated polyacrylonitrile synthesis and characterization. *Arabian Journal of Chemistry.* 7**.** 235-241.

Ellingsen, T., Aune, O., Ugelstad, J. and Hagen, S. (1990) Monosized stationary phases for chromatography. *Journal of Chromatography A.* 535**.** 147-161.

Fontanals, N., Marcé, R. M., Borrull, F. and Cormack, P. a. G. (2010) Mixed-mode ion-exchange polymeric sorbents: dual-phase materials that improve selectivity and capacity. *TrAC Trends in Analytical Chemistry.* 29**.** 765-779.

Ge, S., Liu, Z., Furuta, Y. and Peng, W. (2017) Adsorption characteristics of sulfur solution by acticarbon against drinking-water toxicosis. *Saudi Journal of Biological Sciences.* 24**.** 1355-1360.

Gokmen, M. T. and Du Prez, F. E. (2012) Porous polymer particles- a comprehensive guide to synthesi, characterization, functionalization, and applications. *Progress in Polymer Science.* 37**.** 365-405.

Guerrero-Preston, R. and Brandt-Rauf, P. (2008) Pharmaceutical residues in the drinking water supply: Modeling residue concentrations in surface waters of drugs prescribed in the United States. *US National Library of Medicine National Institutes of Health* 27(3):236-40.

Gupta, A. (2017) Preparation of ethyleneamine functionalized crosslinked poly(acrylonitrile-ethylene glycol-dimethacrylate) chelating resins for adsorption of lead ions. *Separation Science and Technology.* 52**.** 447-455.

Han, L., Sapozhnikova, Y. and Lehotay, S. J. (2014) Streamlined sample cleanup using combined dispersive solid-phase extraction and in-vial filtration for analysis of pesticides and environmental pollutants in shrimp. *Analytica Chimica Acta.* 827**.** 40-46.

He, J. (2013) Crosslinking effect on the deformation and fracture of monodisperse polystyrene-co-divinylbenzene particles. *Express Polymer Letters.* 7 (4) 365–374.

Horie, K., Barón, M., Fox, R. B., He, J., Hess, M., Kahovec, J., Kitayama, T., Kubisa, P., Maréchal, E., Mormann, W., Stepto, R. F. T., Tabak, D., Vohlídal, J., Wilks, E. S. and Work, W. J. (2004) Definitions of terms relating to reactions of polymers and to functional polymeric materials (IUPAC Recommendations 2003). *Pure and Applied Chemistry.* 76 (4) Pages 889–906.

Hwang, K. S., Choi, W. J., Kim, J.-H. and Lee, J.-Y. (2015) Preparation of hypercrosslinked poly(DVB-VBC) particles with high surface area and structured meso- and micropores. *Macromolecular Research.* 23**.** 1051-1058.

Jain, S., Chattopadhyay, S., Jackeray, R. and Singh, H. (2009) Surface modification of polyacrylonitrile fiber for immobilization of antibodies and detection of analyte. *Analytica Chimica Acta.* 654**.** 103-110.

Jamali, M. R., Firouzjah, A. and Rahnama, R. (2013) Solvent-assisted dispersive solid phase extraction. *Talanta.* 116**.** 454-459.

Kiani, G. R., Sheikhloie, H. and Arsalani, N. (2011) Heavy metal ion removal from aqueous solutions by functionalized polyacrylonitrile. *Desalination.* 269**.** 266-270.

Kinney, C. A., Furlong, E. T., Werner, S. L. and Cahill, J. D. (2006) Presence and distribution of wastewater-derived pharmaceuticals in soil irrigated with reclaimed water. *Environ Toxicol Chemical.* 25**.** 7207.

Kummerer, K. (2009) Pharmaceuticals in the environment: sources, fate, effects, and risks. *Environmental Science and Pollution Research.* 17**.** 519-521.

Lee, H.-F., Huang, Y.-C., Wang, P.-H., Lee, C. C., Hung, Y.-S., Gopal, R., Holdcroft, S. and Huang, W.-Y. (2015) Synthesis of highly sulfonated polyarylene ethers containing alternating aromatic units. *Materials Today Communications.* 3**.** 114-121.

Lehotay, S. J. (2011) QuEChERS Sample Preparation Approach for Mass Spectrometric Analysis of Pesticide Residues in Foods. In Zweigenbaum, J. (Ed.) *Mass Spectrometry in Food Safety: Methods and Protocols.* Totowa, NJ. Humana Press.

Li and Stöver (1998) J. Polym. Sci. Part Polym. Chem. 36**.** 1543-1551.

Liang, X. (2013) Synthesis of biodiesel from waste oil under mild conditions using novel acidic ionic liquid immobilization on poly divinylbenzene. *Energy.* 63**.** 103-108.

López, D. E., Goodwin, J. G., Bruce, D. A. and Furuta, S. (2008) Esterification and transesterification using modified-zirconia catalysts. *Applied Catalysis A: General.* 339**.** 76-83.

Lu, X., Huang, D., Yang, X. and Huang, W. (2006) Preparation of narrow or monodisperse polymer microsphere with cyano group by distillation precipitation polymerisation. *Polymer Bulletin.* 56**.** 171-178.

Maria, L. C. D. S., De Aguiar, A. P., Aguiar, M. R. M. P., Jandrey, A. C., Guimarães, P. I. C. and Nascimento, L. G. (2004) Microscopic analysis of porosity of 2-vinylpyridine copolymer networks: 1. Influence of diluent. *Materials Letters.* 58**.** 563-568.

Marjolaine, L., Leanga, S., Berneta, N., Daudinb, J.-J. and Sylvie, N. (2014) Multi-residue analysis of pharmaceuticals in aqueous environmental samples by online solid-phase extraction ultra high performance liquid chromatography-tandem mass spectrometry: Optimisation and matrix effects reduction by quick, easy, cheap, effective, rugged and safe extraction. *Jurnal of Chromatography A.* 11-13.

Martin, H., Frantisek, S., Libor, C., Michal, C. and Petra, K. (2012) Ethanolysis of rapeseed oil by KOH as homogeneous and as heterogeneous catalyst supported on alumina and CaO. *Energy.* 48**.** 392-397.

Miri, K., Abu Much, R. and Gedanken, A. (2011) Optimization of bio-diesel production from soybean and wastes of cooked oil: Combining dielectric microwave irradiation and a SrO catalyst. *Bioresource Technology.* 102**.** 1073-1078.

Moura, B. H. F., Assis, R. H. B., Franco, P. I. B. M., Antoniosi Filho, N. R. and Rabelo, D. (2013) Synthesis and characterization of composites based on polyaniline and styrene–divinylbenzene copolymer using benzoyl peroxide as oxidant agent. *Reactive and Functional Polymers.* 73**.** 1255-1261.

Mousavi Shoushtari, A., Majidi Simakani, A., Akbari, S. and Haji, A. (2014) Citric acid-modified acrylic micro and nanofibers for removal of heavy metal ions from aqueous media AU - Abdouss, Majid. *Desalination and Water Treatment.* 52**.** 7133-7142.

Naveed, D. P. S. and Qamar, F. (2014) Simple UV spectrometric assay of mefenamic acid. *International Journal of Pharmacy and Pharmaceutical Sciences.* 5.364-366.

Pang, J., Shen, K., Ren, D., Feng, S., Wang, Y. and Jiang, Z. (2013) Polymer electrolyte membranes based on poly(arylene ether)s with penta-sulfonated pendent groups. *Journal of Materials Chemistry A.* 1**.** 1465-1474.

Patiño, D., Correa, E. and Acevedo-Morantes, M. (2016) Effect of sulfonation and diethanolamine addition on the mechanical and physicochemical properties of SEPS copolymer. *Journal of Physics: Conference Series.* 687**.** 012056.

Riqueza, E. C., De Aguiar, A. P., De Aguiar, M. R. M. P. and De Santa Maria, L. C. (2007) Thermogravimetric study of some crosslinked copolymers based on poly(acrylonitrile-co-divinylbenzene). *Thermochimica Acta.* 456**.** 128-133.

Riqueza, E. C., Palermo De Aguiar, A., Santa Maria, L. C. and Marques Palermo De Aguiar, M. R. (2002) Modification of porous copolymers network based on acrylonitrile. *Polymer Bulletin.* 48**.** 407-414.

Ruimin, M., Minxiang, W., Qingwei, B., Dong, L. and Yanli, Z. (2018) Improving lead adsorption through chemical modification of wheat straw by lactic acid. *IOP Conference Series: Earth and Environmental Science.* 108**.** 022063.

Samiey, B., Cheng, C.-H. and Wu, J. (2014) Organic-Inorganic Hybrid Polymers as Adsorbents for Removal of Heavy Metal Ions from Solutions: A Review. *Materials.* 7**.** 673-726.

Satilmis, B. and Budd, P. M. (2017) Selective dye adsorption by chemically-modified and thermally-treated polymers of intrinsic microporosity. *Journal of Colloid and Interface Science.* 492**.** 81-91.

Siddiqui, M. R., Alothman, Z. A. and Rahman, N. (2017) Analytical techniques in pharmaceutical analysis: A review. *Arabian Journal of Chemistry.* 10**.** S1409-S1421.

Smigol, V., Svec, F. and Frechet, J. M. J. (1993) Use of polymeric catalysts in the pore-size-specific functionalization of porous polymers. *Macromolecules.* 26**.** 5615-5620.

Sobiesiak, M., Podkościelna, B. and Podkościelny, P. (2016) New functionalised polymeric microspheres for multicomponent solid phase extraction of phenolic compounds. *Adsorption.* 22**.** 653-662.

Socas-Rodríguez, B., Hernández-Borges, J., Herrera-Herrera, A. V. and Rodríguez-Delgado, M. Á. (2018) Multiresidue analysis of oestrogenic compounds in cow, goat, sheep and human milk using core-shell polydopamine coated magnetic nanoparticles as extraction sorbent in micro-dispersive solid-phase extraction followed by ultra-high-performance liquid chromatography tandem mass spectrometry. *Analytical and Bioanalytical Chemistry.* 410**.** 2031-2042.

Socas-Rodríguez, B., Herrera-Herrera, A. V., Asensio-Ramos, M. and Hernández-Borges, J. (2015) Dispersive Solid-Phase Extraction. *In Analytical Separation Science (eds V. Pino, J. L. Anderson, A. Berthod and A. M. Stalcup)*. 5. DOI: 10.1002/9783527678129.

Song, J.-S. and Winnik, M. A. (2006) Monodisperse, micrometer-sized low molar mass polystyrene particles by two-stage dispersion polymerization. *Polymer.* 47**.** 4557-4563.

Subri, N. N. S., Cormack, P. a. G., Md. Jamil, S. N. A., Abdullah, L. C. and Daik, R. (2017) Synthesis of poly(acrylonitrile-co-divinylbenzene-co-vinylbenzyl chloride)-derived hypercrosslinked polymer microspheres and a preliminary evaluation of their potential for the solid-phase capture of pharmaceuticals. *Journal of Applied Polymer Science.* 135**.** 45677.

Tabekh, H., Al-Kurdi, H. and Ajji, Z. (2016) Sulphonation of expanded polystyrene waste with commercial sulphuric acid for potential use in removal of heavy metals from contaminated waters. *Kategorizirani Radovi.* 678.

Tan, L. and Tan, B. (2017) Hypercrosslinked porous polymer materials: design, synthesis, and applications. *Chemical Society Reviews.* 46**.** 3322-3356.

Tanaka, T., Suzuki, T., Saka, Y., Zetterlund, P. B. and Okubo, M. (2007) Mechanical properties of cross-linked polymer particles prepared by nitroxide-mediated radical polymerization in aqueous micro-suspension. *Polymer.* 48**.** 3836-3843.

Trochimczuk, A., Pielichowski, J. and Kolarz, B. N. (1990) Thermogravimetric analysis of acrylonitrile-butyl acrylate-divinylbenzene macroporous terpolymers. *European Polymer Journal.* 26(9). 959-961.

Vergili, I. and Barlas, H. (2009) Removal of selected pharmaceutical compounds from water by an organic polymer resin. *CSIR.* 68(05). 417-425.

Wang, C., Shin, D. W., Lee, S. Y., Kang, N. R., Robertson, G. P., Lee, Y. M. and Guiver, M. D. (2012) A clustered sulfonated poly(ether sulfone) based on a new fluorene-based bisphenol monomer. *Journal of Materials Chemistry.* 22**.** 25093-25101.

William, R. (2013) Infrared Spectroscopy. Management Science University (MSU).

Wojaczyńska, M. and Kolarz, B. N. (1986) Structure and sorption properties of porous copolymers of acrylonitrile and divinylbenzene. *Journal of Chromatography A.* 358**.** 129-136.

Xiong, L., Gao, Y.-Q., Li, W.-H., Yang, X.-L. and Shimo, S. P. (2015) Simple and sensitive monitoring of β2-agonist residues in meat by liquid chromatography–tandem mass spectrometry using a QuEChERS with preconcentration as the sample treatment. *Meat Science.* 105**.** 96-107.

Yang, J., Li, Q., Wang, L., Shao, J., Mei, W. and Wang, L. (2019) Development and application of a dispersive solid-phase extraction method for the simultaneous determination of chloroacetamide herbicide residues in soil by gas chromatography-tandem mass spectrometry (GC-MS/MS). *International Journal of Environmental Analytical Chemistry.* 99**.** 282-296.

Yang, S., Ahn, Y. and Kim, D. (2017) Poly(arylene ether ketone) proton exchange membranes grafted with long aliphatic pendant sulfonated groups for vanadium redox flow batteries. *Journal of Materials Chemistry A.* 5**.** 2261-2270.

Zeleňák, V., Badaničová, M., Halamová, D., Čejka, J., Zukal, A., Murafa, N. and Goerigk, G. (2008) Amine-modified ordered mesoporous silica: Effect of pore size on carbon dioxide capture. *Chemical Engineering Journal.* 144**.** 336-342.

Zhang, J., Lu, Z., Wu, M., Wu, Q. and Yang, J. (2015) Large-scale synthesis and characterization of magnetic poly(acrylic acid) nanogels via miniemulsion polymerization. *RSC Advances.* 5**.** 58889-58894.

Zheng, L., Hou, Y., Li, W., Yang, S., Li, Q. and Yu, Z. (2012) Biodiesel production from rice straw and restaurant waste employing black soldier fly assisted by microbes. *Energy.* 47**.** 225-229.